Course:	**Semiconductor Device Fundamentals**
Level:	**Undergraduate**
Module:	**C**
Test:	**C18**
Type:	**Closed Book, Closed Notes**
Note:	**Available Info/Equation Sheets**

Problem Weighting--- **F-1...32 (4 each part)**
F-2...28 (4 each part)
F-3...24 (4 each part)
F-4...16

F - 1

Using the energy band diagram indicate how you would visualize...

(a) Freeze-out of majority carrier electrons at donor sites as the temperature is lowered toward $0^{o}K$.

(b) Capture of a conduction band electron at a Recombination-Generation site.

(c) Avalanching in a PN junction diode.

(d) A PNP Bipolar Junction Transistor (BJT) under active mode biasing. (Please label the emitter, base and collector regions E, B and C respectively.)

(e) Interfacial traps in an MOS structure.

Sketch an outline of the depletion region(s) in...

(f) a $P^{+}NP^{-}$ Bipolar Junction Transistor under active mode biasing.

(g) an n-channel J-FET where $V_P < V_G < 0$ and $0 < V_D < V_{Dsat}$.

(h) an n-channel MOSFET biased at the pinch-off point ($V_D = V_{Dsat}$). ---Also include the inversion layer in this sketch.

F - 2

The energy band diagram shown in Fig. PF-2 characterizes a junction diode maintained at room temperature. Answer the questions which follow using the information conveyed in the diagram and the data adjacent to the diagram.

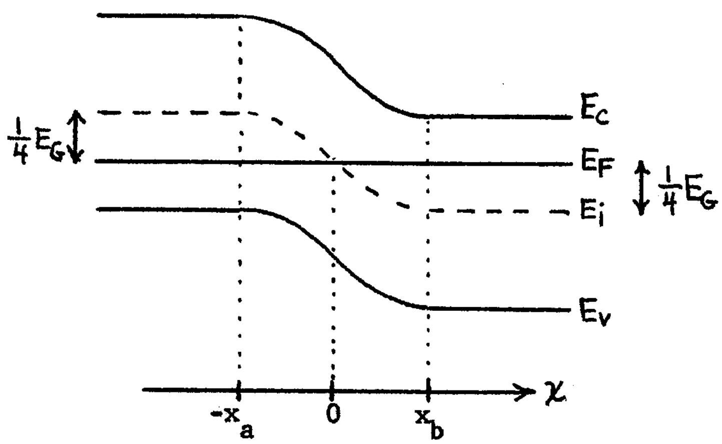

Fig. PF-2

Data

$kT = 0.0255\text{eV}$

$E_G = 1.43\text{eV}$

$K_S = 10.9$

$\epsilon_o = 8.85 \times 10^{-14}$ f/cm

A(area) $= 10^{-2}\text{cm}^2$

$x_a + x_b = 10^{-3}$cm

(a) Assuming a uniform N_A doping for $x < 0$ and a uniform N_D doping for $x > 0$, is the semiconductor degenerate at any point? Explain.

(b) Sketch the electrostatic potential (V) inside the diode as a function of x.

(c) Sketch the electric field ($\mathcal{E}$) inside the device as a function of x.

(d) What is the voltage (V_A) being applied to the device? Explain how you arrived at your answer.

(e) Determine V_{bi}, the built-in voltage. (A numerical answer is required--and you must show how you obtained it.)

(f) Approximately, what will be the junction (or depletion layer) capacitance exhibited by the diode at the pictured bias point?

(g) In the given device is junction breakdown expected to be caused by avalanching or the Zener process? Explain.

F - 3

The d.c. state of an MOS-Capacitor is characterized by the block charge diagram shown in Fig. PF-3. Answer the questions below making use of the information conveyed in the diagram.

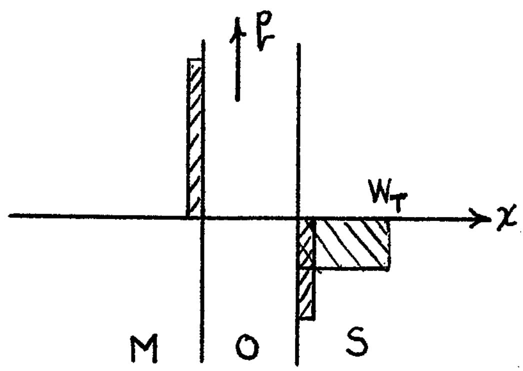

Fig. PF-3

(a) Is the semiconductor N or P-type? Explain.

(b) Is the device accumulation, depletion, or inversion biased? Explain.

(c) Assuming the MOS-C is ideal, draw the energy band diagram corresponding to the charge state pictured in the block charge diagram.

(d) By appropriately modifying the block charge diagram, indicate how the charge state inside the MOS-C is modified when a small-signal high-frequency a.c. signal is applied to the structure.

(e) Sketch the general shape of the high-frequency C-V characteristic to be expected from the structure and indicate by a ⊙ the operating point corresponding to the Fig. PF-3 block charge diagram.

(f) Suppose the MOS-C is biased at the same gate voltage giving rise to the Fig. PF-3 diagram, but is <u>totally deep depleted</u>. Draw the block charge diagram describing the new state of the system.

F - 4

Through ion-implanation it is now possible to effectively create a negative fixed charge (call this new charge Q_I) at the Si-SiO_2 interface. With this Q_I one can cancel out the effects of Q_F, ϕ_{MS}, etc. and successfully build MOSFET's with $V_G = 0$ turn-on voltages.

GIVEN...

(1) Al - SiO_2 - Si structure ($\Phi'_M - \chi' = -0.11$ev)

(2) $N_D = 10^{15}/cm^3$ = Si substrate doping

(3) $V'_T = -1.39$V (V'_T = ideal device turn-on voltage)

(4) No interfacial traps

(5) No mobile ions in the oxide

(6) $Q_F/q = 2 \times 10^{11}/cm^2$ (This is the normal positive fixed charge.)

(7) $x_o = 0.2\mu = 2 \times 10^{-5}$cm

(8) Room temperature operation where $kT/q = 0.0255$V, $E_G = 1.12$eV and $n_i = 8.6 \times 10^9/cm^3$. Also, $K_0 = 3.9$ and $\epsilon_o = 8.85 \times 10^{-14}$f/cm

DETERMINE the ions/cm^2 ($-Q_I/q$) required to achieve a $V_G = 0$ turn-on voltage.

NOTE: As established in the text,

$$\Delta V_G = (V_G - V'_G)\big|_{\text{same } U_S} = -\frac{Q_M \gamma_M}{C_o} - \frac{Q_F}{C_o} - \frac{Q_{IT}(U_S)}{C_o} + \phi_{MS}$$ ← DOES NOT INCLUDE Q_I

where $$\gamma_M \equiv \int_0^{x_o} x\,\rho_{ox}(x)dx \Big/ x_o \int_0^{x_o} \rho_{ox}(x)dx$$

and $$C_o = \frac{K_0 \epsilon_o}{x_o}$$

$$\phi_{MS} = \frac{1}{q}\left[\Phi'_M - \chi' - (E_c - E_F)_\infty\right]$$